

BINARY SYSTEMS OF CORE COLLAPSE SUPERNOVA POLLUTING A GIANT COMPANION

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ABSTRACT

We examine binary systems where the more massive star, the primary, explodes as a core collapse supernova (CCSN) the secondary star is already a giant that intercepts a large fraction of the ejecta. The ejecta might pollute the secondary star with newly synthesized elements such as calcium. We use Modules for Experiments in Stellar Astrophysics (MESA) to calculate the evolution of such SN-polluted giant (SNPG) binaries. We estimate that on average at any given time tens of SNPGs are present in the Galaxy, and ≈ 10 SNPG objects are present in the Magellanic Clouds. We speculate that the high calcium abundance of the recently discovered evolved star HV2112 in the Small Magellanic Cloud might be the result of an SNPG with a super AGB stellar secondary of a mass $\approx 9M_{\odot}$. This rare SNPG scenario is an alternative explanation to HV2112 being a Thorne-Žytkow object (TZO).

Subject headings: stars: massive — stars: peculiar — stars: AGB — stars: evolution — stars:individual: HV2112 — binaries: close — supernovae:general

1. INTRODUCTION

In a recent work Schaffenroth et al. (2015) suggested that the extreme runaway star HD 271791 was polluted by gas from a core-collapse supernova (CCSN). The observed enrichment indicates that HD 271791 had been ejected by a SN explosion of a very massive compact primary, probably a Wolf-Rayet (WR) star. To avoid engulfment during the giant phase of the CCSN progenitor, the polluted star cannot be too close to the CCSN. Hence, to intercept a large fraction of the newly synthesized elements in the CCSN, the companion should be a giant. We here study some aspects of the evolution of such binary systems. We set aside the question whether the CCSN ejecta actually removes a large part of the giant, and no pollution occurs, as claimed by Hirai et al. (2014).

Such a pollution might account for the presence of rare stars with peculiar abundances, e.g., HV2112 (Papish et al. 2015). Levesque et al. (2014) found the evolved star HV2112 in the Small Magellanic Cloud (SMC) to have peculiar abundances. They suggested that the star is a red supergiant (RSG) star, and that the peculiar abundances can be understood if HV2112 is a Thorne-Žytkow object (TZO). TZOs are RSG stars that have a neutron star (NS) at their center (Thorne & Zytow 1975, 1977). The star is powered by accretion on to the NS and/or by nuclear burning in a region away from the NS. The most likely formation scenario for a TZO in this case is a NS that in-spiraled inside the envelope of a RSG star, down to the core. The NS then destroyed the core and replaced the core as the central dense object. Part of the destroyed core formed a temporary accretion disk around the NS.

Tout et al. (2014) examined whether HV2112 is a TZO or perhaps a super asymptotic giant branch (SAGB) star. SAGB stars are stars with a typical initial mass range of $\approx 7 - 11M_{\odot}$ (with dependence on the convective overshoot treatment; Eldridge & Tout 2004; Siess 2006) with an oxygen/neon core undergoing thermal pulses with third dredge up. Tout et al. (2014) argued that SAGBs can synthesize most of the elements that are used to claim that HV2112 is a TZO

through s-process, e.g., molybdenum, rubidium, and lithium. However, they found no way for a SAGB star to synthesize calcium. They suggested that the observed high calcium abundance can be attributed to its synthesis in the temporary accretion disk around the NS, composed of the destroyed core material in the TZO formation process. In such an accretion disk temperatures and densities are high enough for calcium nucleosynthesis (Metzger 2012). The kinetic energy of the disk wind that is required to spread calcium in the giant has enough energy to unbind the envelope, and thus Tout et al. (2014) postulated that the outflow is collimated, hence most of it escapes from the star.

However, it is not clear that a TZO can form at all. Based on earlier studies of common envelope (CE) ejection by jets (Armitage & Livio 2000; Soker 2004; Chevalier 2012), Papish et al. (2015) studied the removal of the CE that supposedly leads to the formation of TZOs. Papish et al. (2015) found that the jets are launched by the accretion disk while the NS is still in a Keplerian orbit around the central part of the core that is still intact. Therefore, they argued, the jets are not well collimated, and the envelope and a large part of the core will be ejected. Papish et al. (2015) speculated that the calcium in HV2112 comes from an explosion of a supernova (SN) while HV2112 was already a giant star, hence could intercept a large fraction of the SN ejecta. The exploding star was just slightly more massive than HV2112 when they both were on the main sequence. In such massive binary systems the lighter star expands to become a giant before the more massive star explodes.

In the present paper we examine in more detail the scenario proposed by Papish et al. (2015). In this SN-polluted giant (SNPG) scenario we specifically study binary systems of two stars that are massive, $\approx 8.5 - 20M_{\odot}$, and are very close in initial masses, $M_{1,0} - M_{2,0} \approx 0.5 - 1M_{\odot}$. The SN explosion of the primary star might pollute the secondary if the two stars are not too far apart. The secondary stars on the more massive end of this range will result in RSG stars with enhanced newly synthesized elements, whereas those at the lower end would become polluted SAGBs. Therefore, we also examine a sub-group of binaries where the secondary also qualifies as a SAGB star, $M_{2,0} \approx 8.5 - 11M_{\odot}$, and examine the ejecta

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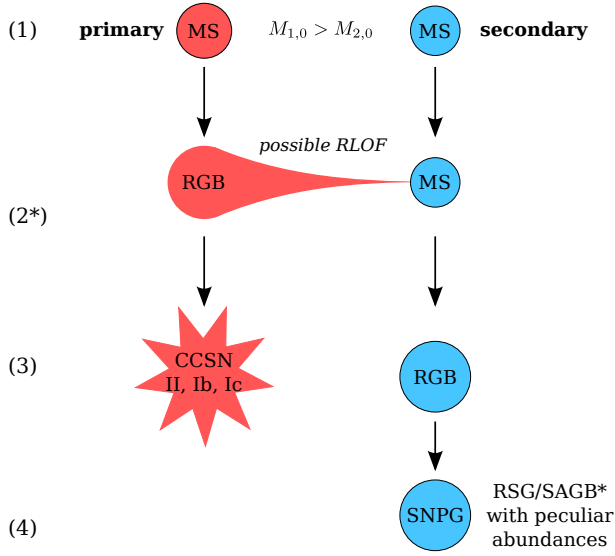


Figure 1. Schematic evolution of the SN-polluted giant (SNPG) binary systems studied here, where the initial mass of the primary (red), $M_{1,0}$, is slightly larger than that of the secondary (blue), $M_{2,0}$. The evolution is plotted from ZAMS (row 1) until the primary star explodes as a core collapse supernova (CCSN) (row 3). During the explosion the primary chemically pollutes the red super giant (RSG) secondary star which then becomes a SN-polluted giant (SNPG) (row 4). Roche lobe overflow (RLOF) is possible once the primary is a red giant branch (RGB) star (row 2). This is possible for an initial separation of $a_0 \lesssim 2.5R_{1,\text{RGB}}$, where $r_{1,\text{RGB}}$ is the maximum radius of the primary during its RGB phase. In such cases the post-transfer secondary star, $M_{2,PT}$, is the more massive star in the system since the two stars are of close initial masses (row 3). Since this possible early mass transfer episode does not influence much the final SNPG outcome, we do not study it here in much detail. The resulting secondary star will be a super asymptotic giant branch (SAGB) star in case its initial mass is $\approx 8.5 - 11M_{\odot}$.

fraction that might be intercepted by the secondary star.

In section 2 we study the binary evolution of such systems. In section 3 we discuss a sub-group of such systems and propose a possible explanation for the calcium enrichment in HV2112. In section 4 we estimate the birthrate of such systems. Our summary is in section 5.

2. BINARY EVOLUTION

We examine the evolution of massive binary systems where on the zero age main sequence (ZAMS) the primary of mass $M_{1,0}$ is slightly more massive than the secondary of mass $M_{2,0}$, as schematically presented in the first row of Fig. 1. We are interested in primary stars that end as CCSNe, which implies an initial primary mass of $M_{1,0} \gtrsim 9M_{\odot}$. To intercept a large fraction of the newly synthesized elements in the CCSN of the progenitor, the companion should be an evolved giant while the explosion of the primary takes place (third row in Fig. 1). The ejecta from the exploding primary star pollutes the secondary which becomes a SNPG (fourth row in Fig. 1), as has been suggested for example for the hyper-runaway star HD271791 (Schaffner et al. 2015). We found that for primary stars in the mass range of $M_{1,0} \approx 9 - 20M_{\odot}$ the secondary must be in the mass range of $M_{1,0} > M_{2,0} \gtrsim M_{1,0} - 1M_{\odot}$, to allow for the SNPG scenario (more details in section 4).

The initial orbital separation cannot be too small since we must avoid the possibility that the secondary would be engulfed by the primary during the primary giant phase. Yet we point out that for the case of close binaries it is possible for the primary to fill its Roche Lobe during its red giant branch (RGB) phase and transfer some of its outer en-

velope to its less massive companion (second row of Fig. 1). We find that for our close systems ($q \equiv M_2/M_1 \approx 1$) RLOF occurs for $R_{1,\text{RGB}}/a_0 \lesssim 0.4$ (Eggleton 1983), where $R_{1,\text{RGB}}$ is the maximum radius of the primary on the RGB. Hence, assuming the initial orbital separation of the system is $a_0 \lesssim 2.5R_{1,\text{RGB}}$, the primary might fill its Roche lobe and transfer the outer layers of its envelope to the secondary star, while the latter is still on the MS. Due to the close initial mass of the stars, in case of mass transfer the post-transfer primary continues to evolve with a lower mass envelope, and the post-transfer (PT) secondary evolves as a star slightly more massive than the initial primary, $M_{1,PT} < M_{2,PT}$. Moreover, since the stars are of close initial masses, as the secondary grows to be the more massive star in the system the orbital separation grows and the mass transfer might cease, at least for some period. We do not go into details of such an early-RLOF phase since it has little importance to the pollution of the secondary and the SNPG outcome. In addition, it is possible that later the secondary will fill its Roche lobe before the primary explodes. If this occurs we might form a common envelope. This is not studied here.

The evolutionary scheme presented in Fig. 1 is significantly different from those in Sabach & Soker (2014) as here there is no reverse evolution, the primary experiences a CCSN explosion, and the secondary is a giant when the primary ends its evolution; these don't hold in the scenarios discussed in Sabach & Soker (2014).

To follow the evolution of each star from zero age main sequence (ZAMS) we use the Modules for Experiments in Stellar Astrophysics (MESA), version 7184 (Paxton et al. 2011), for non-rotating stars. For the lower mass range of the systems studied here we were able to evolve the stars until the formation of an Oe core. We encountered some numerical difficulties at very late evolutionary stages because off-center burning flames make the computation numerically expensive. The omission of the final core collapse has no consequences for our study.

Fig 2 shows the evolution of a representative binary system of the higher mass range evolving according to our assumptions. The initial primary and secondary masses are $M_{1,0} = 20M_{\odot}$ and $M_{2,0} = 19M_{\odot}$, respectively. The system was evolved from ZAMS with solar metallicity ($z = 0.02$), and until the explosion of each star. It is evident that once the primary explodes the secondary is already a red-giant. It is also apparent that during the giant phase of the primary star mass transfer is possible via RLOF, depending on the initial separation of the system (see above). This possibility is not presented here as there is little significance on the SNPG outcome.

We note that there are uncertainties as to whether SN ejecta can enrich a giant companion star. Hirai et al. (2014) find in recent numerical simulations that the shock propagating through the secondary by the SN ejecta can heat the companion. This might lead to the removal of up to 25% of the companion mass by the excess energy in case of a close binary, and could rule out the proposed model. This difficulty might be overcome by non-spherical SN ejecta with a large concentration of calcium and other synthesized elements ejected towards the companion. Another process that can overcome the difficulties posed by the results of Hirai et al. (2014) and allow large quantities of calcium and other heavy elements to be accreted on to the companion is if the newly synthesized elements from the core of the SN expand in dense clumps. Such clumps can penetrate deeper to the star, and stay bound.

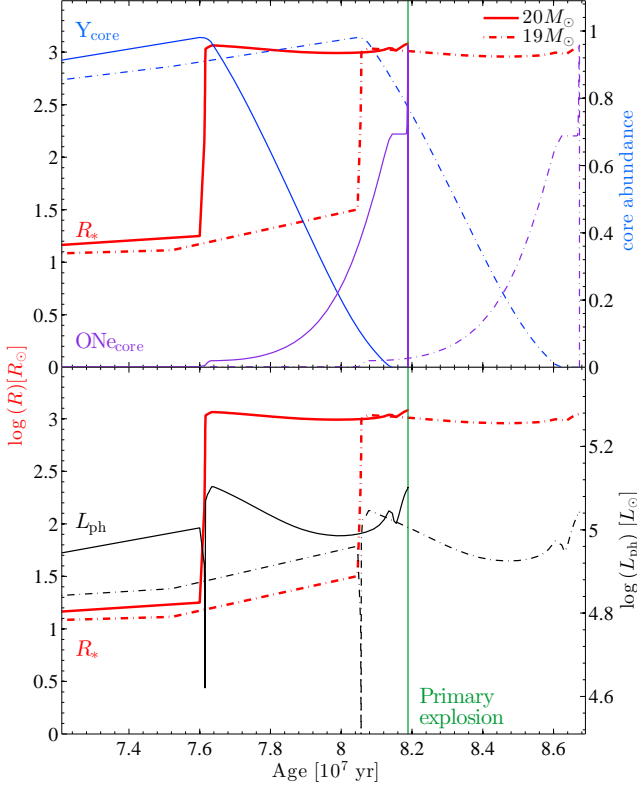


Figure 2. The evolution of a representative system evolved using MESA from ZAMS with solar metallicity ($z = 0.02$). The primary initial mass is $M_{1,0} = 20M_{\odot}$ and the secondary initial mass is $M_{2,0} = 19M_{\odot}$. Each star was evolved until explosion as a core collapse supernova. We present only the late stages of evolution. The solid and dashed lines represent the primary and secondary stars, respectively. Upper panel: The thick-red, blue and purple lines represent the stellar radius (left axes), He fraction in the core, and ONe fraction in the core (right axes), respectively. Lower panel: The thick-red and black lines represent the stellar radius (left axes), and stellar luminosity (right axes), respectively. The primary explosion is marked with a green vertical line, corresponding to the third row in Fig. 1. The primary reaches its final stages of evolution when the secondary is a red giant star. At the late evolutionary stages of M_2 it becomes polluted red duper giant (RSG) with peculiar abundances (forth row in Fig. 1).

An estimation of the overall ejecta fraction intercepted by the secondary star is calculate next in section 3 for the case of a SAGB companion.

3. HV2112 AS A SAGB STAR

We examine a sub-group of SN-polluted giants (SNPGs) where the mass of the secondary during the explosion of the primary is in the range of $\approx 8.5 - 11M_{\odot}$, in order to qualify as a SAGB star (Eldridge & Tout 2004; Siess 2006). We present here a representative case for such systems that might account for HV2112 being a SAGB star. For the SMC metallicity ($Z \sim 0.004$; Diago et al. 2008) Doherty et al. (2015) find that SAGB stars are in an initial mass range of $7.1 - 8.8M_{\odot}$. Accordingly we chose the initial primary and secondary masses, as shown in Fig. 3, to be $M_{1,0} = 9.5M_{\odot}$ and $M_{2,0} = 9M_{\odot}$, respectively. We evolved each star with an SMC metallicity of $z = 0.004$ using MESA.

The initial stellar masses were chosen according to four criteria: (1) The primary is massive enough to explode as a CCSN (triggered by electron capture). (2) The stars must be of close initial masses for the secondary to be an RGB star during the explosion of the primary. (3) The secondary must qualify as a SAGB star at late stages. (4) The evolved SAGB

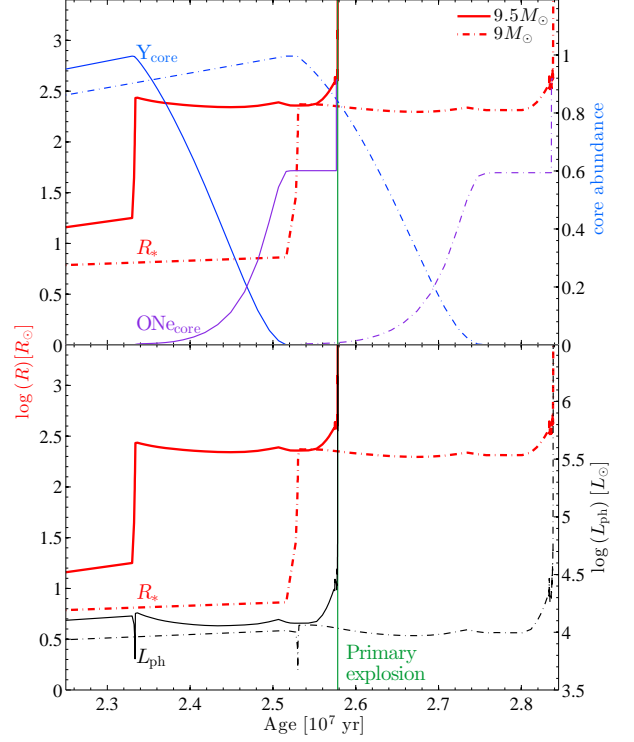


Figure 3. The evolution of a representative system that might account for HV2112. The primary initial mass is $M_{1,0} = 9.5M_{\odot}$ and the secondary initial mass is $M_{2,0} = 9M_{\odot}$. We start the evolution from the ZAMS with SMC metallicity ($z=0.004$) but show here only the late stages. Each star was evolved until late evolutionary stages prior to the explosion as a core collapse supernova. The solid and dashed lines represent the primary and secondary stars, respectively. Upper panel: The thick-red, blue and purple lines represent the stellar radius (left axes), He fraction in the core, and ONe fraction in the core (right axes), respectively. Lower panel: The thick-red and black lines represent the stellar radius (left axes), and stellar luminosity (right axes), respectively. The primary explosion is marked with a green vertical line, corresponding to the third row in Fig. 1. The primary reaches its final stages of evolution when the secondary is a red giant star. At the late evolutionary stages of M_2 it becomes a super asymptotic giant branch (SAGB) star with an ONe core (forth row in Fig. 1).

secondary must agree with the properties of HV2112, e.g., luminosity of $\approx 4.6 \times 10^4 - 1.1 \times 10^5 L_{\odot}$ (Levesque et al. 2014; Tout et al. 2014).

We note that during the final (few $\times 10^3$ yr) stages of evolution the stars seem to exceed the Eddington luminosity calculated for electron scattering opacity. One should take into account that during this stage the opacity in the photosphere is much lower than that for electron scattering. Namely, the star does not reach the Eddington luminosity at the photosphere. Above the photosphere electron scattering might dominate, and mass loss rate must be very high. Our simulations do not include such an enhanced mass loss rate, but this is what we expect to occur.

As the primary star explodes it chemically pollutes the secondary star, now an RGB star with a radius of $\approx 230R_{\odot}$. The polluted secondary continues to evolve into a SAGB star. To account for the calcium abundance in HV2112 Papish et al. (2015) assumed that the giant secondary star intercepted a large enough fraction of the ejecta. We here demonstrate that this is possible. Tout et al. (2014) estimate the calcium mass in HV2112 to be $\approx 10^{-4}M_{\odot}$ from the line ratios presented by Levesque et al. (2014) for the SMC metallicity. For massive stars, $9M_{\odot} \lesssim M_1 \lesssim 20M_{\odot}$, with solar

metallicity exploding as a CCSN the ejected ^{40}Ca mass is $\simeq \text{few} \times 10^{-3} - \text{few} \times 10^{-2} M_{\odot}$. This is up to one hundred times the calcium mass estimated in HV2112. We note that the Ca abundance in the lower range of massive stars $8M_{\odot} \lesssim M \lesssim 11M_{\odot}$, exploding as CCSN hasn't been studied thoroughly for the metallicity of the SMC, hence we use the above estimations of the ejecta in our calculations.

Overall a fraction of $f \approx 0.01$ of the SN ejecta must be accreted on to the secondary. For an accretion efficiency η we have

$$f = \frac{1}{4} \left(\frac{R_2}{a} \right)^2 \eta = 0.01 \quad (1)$$

where a and R_2 are the separation of the system and the secondary radius during the SN explosion, respectively. To account for $\simeq 10^{-4} M_{\odot}$ of ^{40}Ca in HV2112 requires that $\eta \approx 0.25$. In cases where RLOF is avoided at an earlier stage (see section 2) $R_2/a \gtrsim 0.4$ hence $\eta \gtrsim 0.25$.

4. BIRTHRATE ESTIMATION

To estimate the Galactic and Magellanic Clouds (MCs) birthrate of the studied SNPG systems, and the fraction to all potential progenitor of CCSNe we proceed as done by Sabach & Soker (2014). For the initial mass function of the relevant primary we take (Kroupa et al. 1993)

$$\frac{dN}{dM} = AM^{-2.7}, \quad \text{for } 1.0M_{\odot} < M, \quad (2)$$

where A is a constant. For the systems studied here we demand that the initial stellar mass must be

$$M_{1,0} > M_{2,0} \gtrsim M_{1,0} - \Delta M \equiv M_{2,0,\min}.$$

We also assume that the secondary mass distribution is constant in the allowed range

$dN_2 = dM_2/M_1$ for $M_1 > M_2 > 0$. The number of relevant binary systems is given by

$$N_b \simeq \int \frac{dN_1}{dM_{1,0}} \left(\frac{M_{1,0} - M_{2,0,\min}}{M_{1,0}} \right) dM_{1,0}. \quad (3)$$

We find that for primary stars with initial mass of $15M_{\odot} \gtrsim M_{1,0} \gtrsim 9M_{\odot}$ the secondary must be in the mass range of $M_{1,0} > M_{2,0} \gtrsim M_{1,0} - 0.6M_{\odot}$, to allow our evolutionary scenario. For primary stars with initial mass of $20M_{\odot} \gtrsim M_{1,0} \gtrsim 15M_{\odot}$ the secondary must be in the mass range of $M_{1,0} > M_{2,0} \gtrsim M_{1,0} - 1.2M_{\odot}$. This gives

$$N_b \simeq \int_{9M_{\odot}}^{15M_{\odot}} \frac{dN_1}{dM_{1,0}} \left(\frac{0.6M_{\odot}}{M_{1,0}} \right) dM_{1,0} + \int_{15M_{\odot}}^{20M_{\odot}} \frac{dN_1}{dM_{1,0}} \left(\frac{1.2M_{\odot}}{M_{1,0}} \right) dM_{1,0} = 6 \times 10^{-4} AM_{\odot}^{-1.7}. \quad (4)$$

For the progenitors of CCSNe we take all stars with initial mass $M \gtrsim 9M_{\odot}$, for which integration gives $N_{\text{CCSN}} = 0.014AM_{\odot}^{-1.7}$.

Raghavan et al. (2010) estimate a lower limit of 75% for O-type stars to have companions. We take a typical fraction $f_b \simeq 0.8$ of O-type stars to be in binary systems with an orbital separation less than $700AU$, and the relevant binary population of massive stars to span over a range of 4 orders of magnitude (from $a_{\min} \simeq 0.1$ to $a_{\max} \simeq 1000AU$)

with an equal probability in the logarithmic of the orbital separation. For the pollution of the secondary by the primary to take place, the relevant orbital separation distribution is $a \simeq 2 - 6R_2 \simeq 500 - 1500R_{\odot}$ (as we can not completely rule out some mass transfer, accounting for the lower limit). We find the orbital separation distribution to span over $\simeq 0.5$ dex.

Accordingly, the probability of a binary system to be in the desired orbital separation is $f_s \simeq 0.5/4 = 1/8$. This is a crude estimate as we took an order of magnitude value for the relevant orbital separation range. We also note that if the eccentricity of the system is considered the initial separation range is even larger.

The fraction of the SNPG systems studied here to the number of CCSNe progenitors is

$$\frac{N_{\text{systems}}}{N_{\text{CCSN}}} \simeq \frac{N_b}{N_{\text{CCSN}}} f_b f_s \simeq 4.3 \times 10^{-3}. \quad (5)$$

Using the CCSN rate in the Galaxy $\simeq 0.014\text{yr}^{-1}$ (Cappellaro et al. 1997), we estimate the Galactic birthrate of such systems to be $\simeq 6 \times 10^{-5}\text{yr}^{-1}$. From the lifetime of the polluted secondary stars studied here from the primary explosion to the secondary explosion, $\simeq 10^6\text{yr}$ (Fig 2), we estimate that on average ≈ 60 such SNPG systems exist in the Galaxy at any given time. Maoz & Badenes (2010) estimate the SN (SNIa+CCSN) rate in the MCs to be $2.5 - 4.6 \times 10^{-3}\text{yr}$, and the CCSN rate to be $\simeq 2.5$ times more than the SNIa rate. From the lifetime of the polluted secondary star we estimate that on average ≈ 10 such systems exist in the MCs at any given time.

For the sub-case of SAGB polluted giants the recurrence of objects such as HV2112 is smaller since the SAGB lifetime is a few 10^5yr (Fig 3; Doherty et al. 2014). We estimate that only 1-3 objects will be found in the SMC. If a large number of such objects will be found, probably neither our model nor the TZO model will be applicable. We note that the uncertainties in our estimates are very large, but non-the-less the conclusion that such SNPG objects are rare is robust.

5. DISCUSSION AND SUMMARY

We have studied some properties of binary systems where the secondary star is already in its giant phase when the primary explodes as a core collapse supernova (CCSN; Fig. 1). For this to occur the initial mass of the secondary star should be only slightly, by about 5% and less, below the initial mass of the primary.

From the results of section 4 this case occurs in about 2% of all CCSNe. This implies that observations of the post-explosion site can reveal that a giant star still exists there. With better sky coverage and more SNe in relatively close galaxies, such cases must be eventually detected.

We then discussed a specific type of such systems where the orbital separation is such that the secondary star can intercept a large fraction, about 1%, of the SN ejecta. If the secondary envelope is not completely ablated by the ejecta, the secondary becomes polluted with metals from the SN; we term this a SN-polluted giant (SNPG) scenario. In section 4 we estimated the SNPG scenario might occur in about 0.4% of all CCSNe. The secondary then lives for some time before it explodes. We estimated that at any given time there are about 60 SNPG stars in the Galaxy and about 10 SNPG stars in the Magellanic clouds. If we allow for a lower chemical pollution, then the orbital separation can be larger and the number of SNPG systems increases.

We used the SNPG scenario to address the large calcium abundance of the evolved star HV2112 in the Small Magellanic Cloud (SMC). Tout et al (2014) find that a super-AGB star can account for the peculiar abundances of HV2112 besides that of calcium. Levesque et al. (2014) and Tout et al. (2014) argued that the high calcium abundance is best explained if HV2112 is a Thorne-Żytkow object (TZO). Papish et al. (2015), on the other hand, argued that it is impossible to bring a NS to the center of a giant star since the entire envelope and part of the original core will be ejected by the jets that are launched by the NS as it in-spirals (Armitage & Livio 2000; Soker 2004; Chevalier 2012). Instead, Papish et al. (2015) speculated that the high calcium abundance might be explained by pollution (enrichment) from a more massive companion that had already exploded as a CCSN. Based on our finding we conclude that the SN pollution scenario is much more likely than the TZO explanation for HV2112.

The evolutionary routes discussed here and in Papish et al. (2015) have potential relation to some exploding and erupting astrophysical objects.

(1) *Explosion with jets*. The process by which the in-spiraling NS launches jets and ejects the envelope and core is very rapid, and will be observed as an explosion (Chevalier 2012). It is quite likely that *all* CCSNe have exploded by jets launched by the newly formed NS (or black hole) at their center, as in the jittering-jet mechanism (Papish & Soker 2014; Gilkis & Soker 2014). Hence, the NS-core merger might be wrongly attributed to a CCSN with large pre-explosion mass loss (Chevalier 2012).

(2) *Intermediate Luminosity Optical Transient (ILOT) 1*. If the NS ejects the entire envelope but does not merge with the core of the RSG star, then the outburst will be much less energetic. The total energy will be of the order of the binding energy of the envelope. The luminosity of the outburst will be much below that of a SN, but more than that of a nova. The outburst will be classified as an ILOT event. We note that the in-spiraling of a WD companion to the core of a giant star can also lead to an ILOT event (Sabach & Soker 2014). Tylenda et al. (2013) already suggested that the transient OGLE-2002-BLG-360 is an ILOT (which they termed a red transient) in the process of a final merger of a common envelope evolution.

(3) *ILOT 2*. If an early stage of RLOF takes place once the primary is a red giant, the mass transfer from the more evolved star to the secondary star occurs in an unstable manner over a short time, tens of years and less, this event can be classified as a luminous blue variable (LBV) major event, or as an ILOT (Kashi & Soker 2010).

(4) *Peculiar Superluminous CCSN*. In the proposed scenario for SNPG the secondary is already a giant when the primary explodes. It is quite possible that the secondary will be as

bright as the primary. For example, in the binary system presented in Fig. 2 the luminosities of the two stars just before the primary explosion are $L_1 = 1.26 \times 10^5 L_\odot$ and $L_2 = 1.02 \times 10^5 L_\odot$. We expect also massive CSM, as not all mass is accreted by the secondary. The collision of SN ejecta with the CSM will form a superluminous SN, but the presence of a post-explosion giant remnant will make it a peculiar CCSN.

Our present study adds to the variety of peculiar astrophysical objects that might be related to peculiar eruptions and explosions.

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